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Employing Customer Value Criteria to Address Networks of Contradictions in Complex Technical Systems

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Abstract

The diffusion of TRIZ in the industry is still under the expectations of the scientific community. According to authors' experience, barriers to industrial adoption are constituted, among the others, by difficulties in approaching problems characterized by tangled networks of parameters and, consequently, very large number of contradictions.
The most tailored tools to face this problem aim at managing networks of contradictions. They try to establish the starting point for an effective problem solving process. The task suffers from subjective evaluations or difficulties with applying complex algorithmic procedures. Besides, the existing approaches overlook the potential benefits descending from overcoming each single contradiction. The authors illustrate a strategy to prioritize technical contradictions, which includes metrics concerning customer value. More specifically, the implemented criteria feature the probability of succeeding in the marketplace. Thus, a business perspective is introduced in the problem solving process. The proposal has been experimented through an application to a mature phase included in the manufacturing process of pharmaceutical tablets. Said production phase, taken as the reference technical system, figures out 239 different contradictions. The application of the developed approach allowed to individuate contradictions whose solution has considerably influenced the technical evolution of the treated industrial sector.

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Keywords: TRIZ, networks of contradictions, customer value, prioritization of contradictions, pharmaceutics industry

1. Introduction

Nomenclature and acronyms

C/E_{typ}	Kind of effect of the CP vs. an EP – direct/indirect
C_{EP}	Relevance of an EP
CP	Control Parameter
EP	Evaluation Parameter
HF	Harmful Function
i_{CPvsEP}	Magnitude of the influence of a CP towards an EP
NoC	Network of Contradictions
NoP	Network of Problems
OTSM	General Theory of Powerful Thinking
Pb	(Sub)Problem
PR	Priority of a contradiction
PS	Partial solution
$QTY_{EP/CP}$	Occurrences of the EP/CP
R_{EP}	Relevance of an EP
RES	Resource/cost
TC	Technical Contradiction
TS	Technical System
UF	Useful Function
X_{TC}	Importance of a Technical Contradiction
Y_{TC}	Universality of the TC
Z_{TC}	Quantity of EP couples connected to the same CP
α_{CP}	Impact of the CP on the couple of EPs

As it is well known, the design process involves problems that cannot be solved in a simple way. On the contrary, many systems are characterized by intrinsic complexity. Each time an existing system needs improvements in terms of better

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performances or mitigation of undesired effects, or a new system has to be designed in order to carry out the function requested by the super-system, the task to deal with is commonly featured by a set of interconnected problems. By now, it is acknowledged by the literature and by practical evidence that adopting systematic methods simplifies the problem solving process, so as to help the designer with managing the tangled resolution path.

Among the many systematic methods to support design activities, with a specific focus on the conceptual design phase, TRIZ ranges among the most prominent ones thanks to its demonstrated effectiveness. Despite its widely accepted capabilities, one of the most recognized weaknesses of Altshuller's theory and toolkit concerns the difficulty with dealing with very complex problems. It is well known that TRIZ, or rather what is more specifically called Classical TRIZ, can be considered as a toolbox from which the designer, based on their knowledge and experience, can choose the most suitable instrument time by time.

Among all the tools belonging to the TRIZ body of knowledge, ARIZ can be considered as the hardest to use, but, thanks to its algorithmic structure, it is the only one capable of leading the designer throughout the resolution steps [1]. However, despite its recognized effectiveness, ARIZ lacks proper means to work with complex problems too. Indeed, ARIZ can be employed starting from the identification of a single technical contradiction. This implies that ARIZ can be adopted when designers are supposed to deal with a single problem. Nevertheless, as already mentioned, a problem can be seldom modelled as a single contradiction in practice.

The present paper deals with these deficiencies. In particular, it discusses the strategies tailored to lead towards the identification of a focal contradiction, viable to constitute the most suitable starting point for addressing the problem solving process in complex systems. From insights into the literature (Section 2), it emerges that the most effective, although not widely spread, existing techniques suffer from subjective designers' decisions. Section 3 presents a candidate method for prioritizing contradictions, whose subjectivity issues are overcome by criteria based on the kinds of enhanced performances, whose effect on business success and customer value is assessed on previous studies. In Section 4, the authors simulate the employment of the modified method for a very complex situation. More specifically, the investigated technical system regards a phase of the process that transforms drug powders into grains for the manufacturing of pharmaceutical tablets. By knowing the evolution of the studied system, the authors point out how the overcoming of the individuated contradiction has truly dictated the development trends of the treated production process. The results, although promising, clearly require further verification, also because of the theoretical and practical weaknesses that are discussed in Section 5. The same section summarizes the outcomes of the study and introduces future work.

2. Contributions from the TRIZ community to deal with complex problems: a review

Given the highlighted deficiencies with regard to complex problems, Genrich Altshuller together with Nikolai Khomenko began to develop a new methodology capable of managing more complex situations. Such an evolution of Classical TRIZ, still under development, is named OTSM-TRIZ (a Russian acronym for the General Theory of Powerful Thinking) [1]. It allows to manage the decomposition of a complex problem into elementary sub-tasks and to conduct their resolution in an orderly and systematic way. A thorough comparison between Classical TRIZ and OTSM-TRIZ is described in [2], which highlights the benefits of the latter. Its approach named Problem Flow Network is based on a plurality of networks. The first one is the Network of Problems (NoP). This tool lets decompose the main problem in a set of sub-problems and to link them in order to maintain the complexity of the system, but allowing, at the same time, to work with a single simple problem each time. The result of the NoP is a graph composed by problems and partial solutions, with the main problem at the top; every branch of the network represents the development of the solutions for each sub-problem.

According to OTSM principles, it is possible to build a second net from the NoP, called the Network of Contradictions (NoC), where all the contradictions that can be extracted from the NoP are collected (see Fig. 1). It may happen that solving a contradiction related to the superior part of a NoP branch invalidates a great number of conflicts. However, concerning the NoC, a new problem arises: which one, among all the contradictions concealed behind a complex problem, has to be faced at first? In case the time is not enough to analyze and solve all of them, which are the criteria for selecting the "best" contradiction?

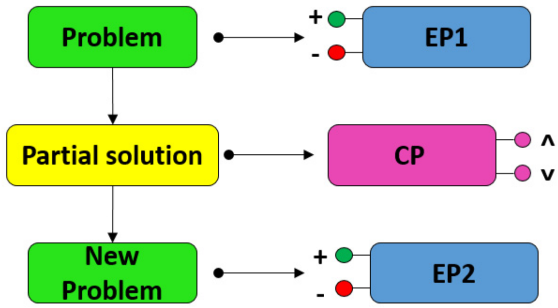

Fig. 1. Extraction of concepts from a Network of Problems to build a Network of Contradictions.

Up to now, the TRIZ literature was not so prolific concerning such questions. Indeed, only few contributes have taken into account such a topic. In [3], Cavallucci, Rousselot and Zanni propose an approach that guides the problem solving process to the elicitation of a set of Technical Contradictions (TCs). Overcoming those TCs should provide the greatest benefits according to the purpose of the problem analysis. They extract this set of TCs out of a NoC by considering three different indexes:

- Importance;

- Universality;
- Amplitude.

Importance (X_{TC})

Its definition takes into account both the impact (αCP) of the CP on the couple of EPs and their importance (C_{EP}) to the scope of the analysis. The related formula follows:

$$X_{TC} = \alpha_{CP_i} \cdot \left(C_{EP_j} + C_{EP_k} \right) \quad (1).$$

Universality (Y_{TC})

Its definition takes into account the occurrences (QTY_{EP}) of the EPs into the body of the TCs composing the NoC. The formula to calculate Universality index is:

$$Y_{TC} = QTY_{EP_j} + QTY_{EP_k} \quad (2).$$

Amplitude (Z_{TC})

This index takes into account the quantity of EP couples that are related to the same CP in the whole body of TCs:

$$Z_{TC} = QTY_{CP_i} \quad (3).$$

A Cartesian coordinate system, where each dot is related to a TC, organizes these indexes as follows:

- Importance (X_{TC}) on the x-axis;
- Universality (Y_{TC}) on the y-axis;
- Amplitude (Z_{TC}) as the radius of dots in the plane.

The designer is supposed to collect the most promising TCs to overcome in the top right corner of such a diagram in order to make the system evolve with the greatest success chance. However, this method gives just preliminary indications about which group of contradictions should be analyzed and solved at first, but it leaves the final choice in charge of the design team.

In [4], the authors propose a different algorithm for extracting the most important contradiction in the whole body of the NoC in order to identify the best opportunity for innovating the technical system and to speed up the solving process by reducing the need for iterations.

Once the NoP has been validated, it is possible to elicit the characteristic parameters of the technical system with the help of field experts or relying on the knowledge acquired during the investigation. The extraction of parameters from the NoP should be organized as follows, mirroring the scheme of Fig. 1:

- each sub-problem (Pb) identifies an expectation that has not been completely satisfied; at least one Evaluation Parameter (EP) can be recognized to measure the degree of satisfaction of such expectation;
- each Partial Solution (PS) elicits at least one way to tackle a sub-problem; at least one Control Parameter (CP) can be associated to the feature exploited to address the related problem.

Once all the contradictions have been extracted from the NoP, the algorithm suggests ranking the EPs according to their relevance for the purpose of the project. For this reason, the algorithm organizes parameters according to a specific set of input variables that further detail their characteristics. More specifically, EPs are clustered according to the following variables set by the user:

- EP type: expresses a link to the Law of Ideality Increase: an EP may refer to the delivery of an Useful Function (UF), of a Harmful Functions (HF) or to Resources/Costs (C);
- EP relevance (R_{EP}): describes the importance of the parameter. The higher the value of R_{EP} (from 1 to 3), the bigger its importance for the objectives of the project.

Similarly, CPs can be organized according to the following classification:

- CP resource: specifies what is the kind of resource (among Space, Time, Information, Material and Energy) that characterizes the parameter;
- CP cost: this value takes into account the economic expenses (e.g.: 3 relates to high costs, 1 to low costs) required to change the current CP with a new one with better capabilities to leverage EPs.

Finally, the cause-and-effect relationship in a CP/EP can be further detailed as follows:

- Impact (i_{CPvsEP}): describes the influence exerted on an EP by a CP. It assumes value 2 with a strong impact; 0.5 with an intermediate impact; 0 with a poor impact and 1 when the impact is unknown but present.
- Cause/Effect relationship (C/E_{typ}): it is a qualitative index that takes into account whether the relationship between CP and EP is direct (+1) or inverse (-1).

Then, a new set of values is automatically calculated and assigned to each parameter for all the TC-triads (CP, EP1, EP2). The algorithm for selecting the most promising TC among the whole set of the NoC is based on three hierarchical subtasks that exploit some of the above-mentioned indexes.

1. Extract a set of TCs having couples of EPs that provide the best results for the objectives of the problem solving process (Criterion A: Choose the TCs having the highest TC relevance, 6 or less).
2. Process the set of extracted TCs according to the desired level of TS modification (Meta-criterion B). When it is necessary to achieve the maximum satisfaction for both the conflicting EPs, it is first necessary to keep the TCs having the highest TC overall index (Criterion B1) and, subsequently, choose the contradiction characterized by the CP less connected to other EPs (Criterion B2). When the TS requires just minor modifications, the above-mentioned criteria must be taken into account in inverse order.
3. For the selected TC, define the value of the selected CP that provides the best outcomes for the whole TS and whose modification generates minimal side effects.

(Criterion C: among the TCs picked up during step 2, choose the one having the highest absolute value, thus -1 or 1, in coherence with "ARIZ step 1.4 index).

3. A proposal to overcome subjectivity in the prioritization of contradictions

The last method [4] can be seen as a reference for accomplishing the task of prioritizing contradictions in complex systems with a tangled network of relationships among parameters. The most evident weakness refers to the presence of subjective evaluations to assign values for the involved indexes. Subjectivity affects *REP* particularly.

Generally speaking, the importance of an EP is related to its capability of fulfilling customer requirements and, thus, generating satisfaction. When a contradiction is overcome, no trade-off between previously conflicting EPs takes place and, as a consequence, the performance of both EPs can be increased (see Fig. 2, big arrows).

From this observation, it can be implied that the most favorable contradiction to solve is featured by the possibility of displaying optimal values for two EPs, both capable of affecting customer satisfaction to a considerable extent. In these circumstances, the problem concerns the possibility of measuring the impact of performance growths with respect to EPs couples, especially in the absence of market information or reliable results from customer surveys, like in [5].

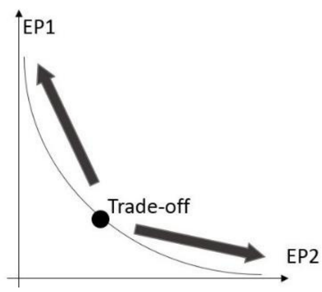

Fig. 2. Model of a contradiction between two EPs: the arrows indicate the two extremes of the contradiction (exaggerated conflicts as for ARIZ85-C).

3.1. A candidate framework to assess the repercussion of solving contradictions

Some research activities have attempted to assess the extent to which circumstanced modifications of product characteristics contribute to the achievement of market success. In [6], the chances of thriving for a new product profile are estimated according to twelve factors viable to describe the deviation from a seeded standard. In particular, the recalled transformations are described in terms of performance improvements or drops, introduction of unprecedented benefits, disregard of previously relevant competing factors. The explanatory factors are not subjective terms, because they do not require any evaluation from the customers' side, by referring to product performances exclusively. Business success is just the dependent variable used in a statistical regression, which has taken into account 92 cases well featuring both thriving product innovations and market failures.

From a TRIZ perspective, the modifications occurred to a system when a contradiction is solved imply significant improvements related to two different factors. In this sense, the overcoming of a contradiction mirrors the enhancement of a pair of performances, if we put forward a comparison with the framework described in [6]. Still according to [6], these enhancements contribute in the achievement of market success to a different extent, if different aspects of involved parameters are considered. More in detail, product requirements are clustered similarly to the above EP types. They are indeed classified into expected UFs, attenuation of HFs, reductions of RES' consumption. Attained improvements of these kinds of parameters participate in increasing success probability, as in the followings (the higher the index extracted from statistical inference the better):

- UF parameters: 0.97
- HF parameters: 1.75
- RES parameters: 0.41

Although the above terms are used in the original framework with a different mathematical formulation, the rank among the typologies of factors are assumed as valid in the present paper for attributing the relevance to EPs.

3.2. A strategy to prioritize contradictions

According to the reference method for prioritizing contradictions and the candidate measures to assess the impact of EPs, a possible strategy to individuate reference dichotomies is the following:

1. Describe the investigated technical system in terms of CPs and EPs.
2. Identify the relationships between CPs and EPs, by particularly taking into account: a) if any univocal variation of a CPs results in improving or worsening any given EP in terms of customers' desirability (C/E_{typ}); b) the extent of said relationships (where extant), as expressed through i_{CPvsEP}.
3. For any individuated contradiction (triads constituted by a CP and two EPs, having opposite C/E_{typ} indexes), classify each listed EPi (direct benefits UF, reduction of harmful functions HF or resources channeling RES) and, in virtue of such a categorization, assign the matching $R_{EP}(EPi)$ according to terms shown in Subsection 3.1.
4. Identify the most urgent contradictions to be solved, i.e. those involving strong relationships between a CP and the connected EPs, as well as high relevance coefficients of the involved EPs, thus HFs having priority over UFs and RESs. The priority of a contradiction *PR* involving a given CP and two EPs, namely EPa and EPb, can be expressed through the following:

$$PR(a,b) = i_{CPvsEPa} \times R_{EP(a)} + i_{CPvsEPb} \times R_{EP(b)} \qquad (4).$$

With reference to the above description of models to prioritize TRIZ conflicts, Fig. 3 graphically displays the criteria that are employed in the present proposal and in the strategies illustrated in [3] and [4] in a simplified way, pointing out which indicators are shared and which ones are original.

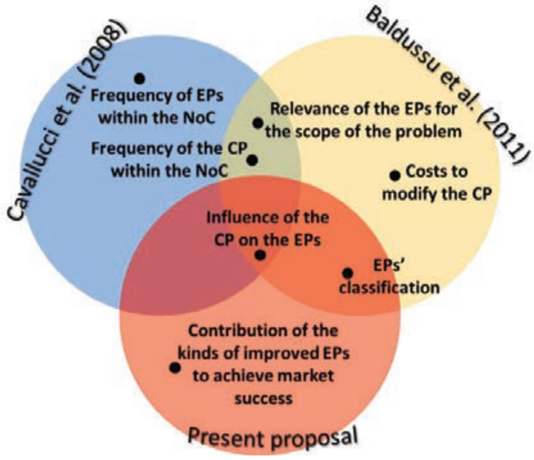

Fig. 3. Overview of the criteria employed by the proposed and existing approaches to prioritize contradictions.

4. Case study

The above approach has been tested with an ex-post approach to an existing case study in the field of manufacturing processes for pharmaceutical tablets. This choice is consistent with the overall purpose of the approach. Market appraisal, indeed, can be tested just once products appear in the market arena. A rigorous validation of the procedure for selecting contradictions would consist in solving each extant dichotomy and verifying the market effect of each new version of the technical system. This testing approach results clearly unfeasible and, therefore, the authors implemented a roundabout strategy to get preliminary evaluations of the reasonableness of the present proposal.

In order to check the overall applicability of the approach and to start gathering indications about its potential usefulness, the authors have therefore chosen two different generations of technologies for pharmaceutical granules separation: vibrating sieves and cyclonic separator. The results obtained from the application of the approach to the first technological generation should show that the prioritized technical contradiction, if solved, improves the market appraisal by leading to a new kind of machine.

In the former technology, granules and powders move along a vibrating surface with calibrated holes working as a sieve. The latter exploits gravity and laws of motion for accelerated particles, so that particles having different mass separate from each other.

In order to avoid the introduction of biases towards the satisfaction of the objectives, the characterization of the vibrating sieves has been borrowed from previous studies [7]. The technology of vibrating sieves was characterized by 11 CPs. They are the key design variables that the related dominant design leverages in order to achieve the desired functionality with reasonable efforts and side effects. For what concerns EPs, 21 main requirements were considered as the main factors characterizing the different generations of technology. According to the pre-defined cause and effect relationships between CP and EP couples, a total amount of 239 contradictions provide evidence of the complexity of the problem at hand.

The criteria defined in Section 3 have been used to process this set of contradictions, leading to the selection of the conflicts that are supposed to be prioritized in light of improving the market appraisal for the proposed solution. The most critical contradiction, as it arises from the individuation procedure, is summarized in the model depicted in Fig. 4. Not surprisingly, both EPs involve undesired effects that take place during the sieving process. The same sample of contradictions has been processed through the procedure described in [4], giving rise to 8 different conflicts, not comprising the dichotomy of Fig. 4.

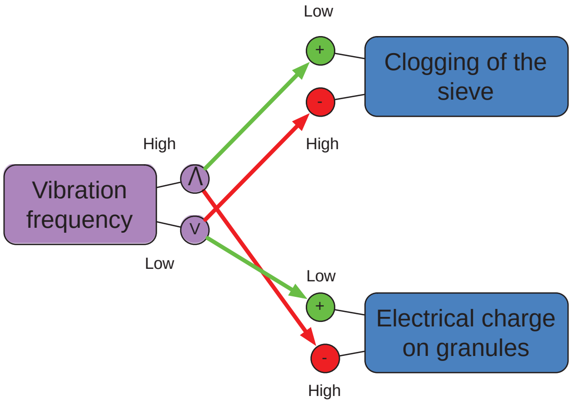

Fig. 4. OTSM-TRIZ Contradiction consisting in the most relevant problem to be solved to improve the market appraisal of future solutions.

Both the EPs of Fig. 4 have paramount importance in the management of a properly working plant. When a sieve is clogged, the production needs to be stopped for maintenance, since the separation process selects granules having an off-design size, which results in tablets of poor quality incurring in phenomena of de-capping and lamination. Residual electrical charge on particles, in turn, might alter the effect of compression forces on granules, increasing the influence of electromagnetically reacting forces that work against the mechanical bounds created once granules get compressed with each other. Tablets of poor quality imply more frequent needs to stop the manufacturing line to clean clogged sieves and to periodically remove surface charges from those interfaces that come into contact with granules (again, the calibrated sieve). At a higher organizational level, this affects the efficiency of plant operations that finally results in lower incomes.

The cyclonic separation technology overcomes the above dichotomy by simply exploiting a working principle that does not work with vibrations. The tribo-electrical effects due to the contact between particles in the tangentially accelerated airflow of the cyclone and between air and particles significantly decreases, resulting in a lower residual charge on granules' surface at the end of the separation. Clogging effects, considering the above working principle, are completely eliminated and the cyclone body needs to be cleaned just in case of production shifts (e.g. when the pharmaceutical formulation changes between production batches).

Both the above aspects represent a strength of this technology in comparison with vibrating sieves. Besides, the increasing number of manufacturing lines adopting the cyclonic separator witnesses the success of this technology. In this sense, the solution of the contradiction highlighted by the proposed procedure is clearly an important driver for the evolution of the treated manufacturing process.

5. Discussions and conclusions

The paper has illustrated a candidate strategy for prioritizing contradictions in complex problems. The assumption underpinning the presented roadmap stands in picking up conflicts between parameters, whose enhancements can contribute in customer satisfaction largely. This condition is met when a CP influences two EPs considerably and their improvement plays a relevant role in the success chances of the new product generation in which the analyzed contradiction is overcome. Whereas the amplitude of the influence of CPs on EPs can be evaluated through the knowledge of the physical principles governing the treated system [4], the capability of enhanced EPs to impact on customer value cannot be assessed unless designers make reference to business or market information. The presented strategy implements the findings from a research activity aimed at anticipating the success likelihood of radical innovations [6], which claims the advantages of working on the attenuation of undesired effects rather than on other typologies of improvements. From this viewpoint, authors' proposal introduces a-priori metrics in the contradictions' prioritization task, which allows to avoid subjective evaluations of the design team, biased market information or unreliable results of customer surveys.

The strategy has been tested through a case study featuring a traditional process for graining pharmaceutical powders. Within a tangled network of CPs and EPs, the proposed procedure has permitted to individuate a contradiction that has been effectively solved along the evolution of manufacturing technologies providing consistent advantages in the pharmaceutical industry. The experiment has provided preliminary evidence about the reasonableness of the metrics introduced within the present proposal, but it features some limitations. As explained in Section 4, an ex-post application of the method resulted as the only chance to conduct a preliminary industrial test. This implies at least two drawbacks. First, the applicability of the method is not fully verified, since a simulation of the use of the proposal was performed; however, the authors are confident about the applicability of the strategy, since industrial subjects require just their knowledge in the field in order to extrapolate the required variables (relationships among parameters, kind of benefits attained through the EPs). Second, it is not possible to affirm with certainty whether the individuated contradiction is the one that should have been prioritized at the time in which vibrating sieves represented the dominant design in the drug processing industry. On the other hand, as already highlighted, the overcoming of the individuated contradiction has resulted in a significant technological progress. At the same time, the number of contradictions to be prioritized has dropped from 8 to one, if we make a comparison with the antecedent procedure.

Further limitations concern theoretical issues, given the experimental matching of technical and business-related information. It is worth pointing out the possible pitfalls of combining different sorts of criteria, with a particular reference to the employment of metrics that descend from empirical evidences about complex phenomena, such as the reasons leading new products to thrive in the marketplace. Moreover, the metrics for various kinds of product improvements (increasing benefits, attenuating harmful functions, limiting resources' consumption) have been extracted by examining industrial successes and failures that refer to radical innovations and more specifically to New Value Propositions. This said, from a theoretical point of view, some circumstances could invalidate the usability of the cited metrics. For instance, this situation could be faced when the overcoming of contradictions does not lead to significant repercussions in terms of perceived customer value, or, in other words, the elimination of a conflict gives rise to a mere technical improvement or to an innovation that could be classified as incremental. Many case studies analyzed in [6] are described by several transformations of product attributes, while the solution of a contradiction is featured in terms of two modifications only, i.e. enhancements in terms of two EPs (see Fig. 1).

Given these limitations, the planned testing campaign of the proposed strategy is intense, in order to compensate theoretical weaknesses with experimental findings. Additionally, the authors will work on improvements of the procedure, so as to face possible cases in which a plurality of contradictions will be featured by the maximum value for the priority term. A slight different strategy will focus on the potential effects of releasing physical instead of technical contradictions, which is supposed to involve more than two EPs at once.

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